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ELECTRICAL RESISTIVITY DATA AND BIBLIOGRAPHY ON TITANIUM AND TITANIUM ALLOYS

John T. Milck

Hughes Aircraft Company

Prepared for:

Air Force Materials Laboratory

March 1970

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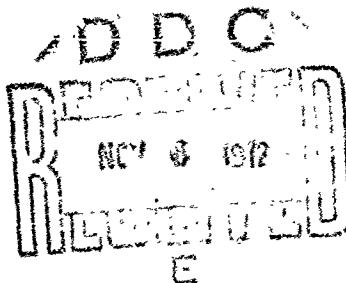


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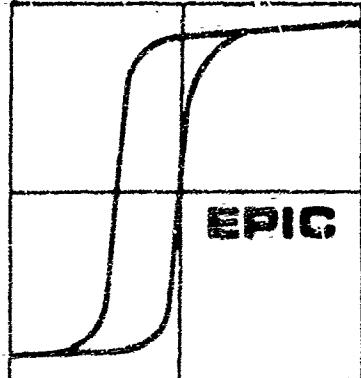
ELECTRICAL RESISTIVITY DATA AND BIBLIOGRAPHY  
ON  
TITANIUM AND TITANIUM ALLOYS

John T. Milck

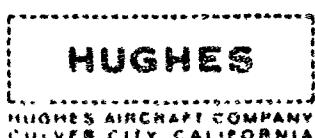


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**ELECTRONIC  
PROPERTIES  
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## INTRODUCTION

This interim report has been prepared in response to a number of requests for electrical properties information on titanium and its alloys. It does not, however, represent a comprehensive search of the literature, but does represent a fairly useful collection of data for design purposes.

Titanium has proven itself to be a very versatile metal (in the unalloyed as well as alloyed condition) for both military and non-military applications. Commercially pure titanium and the various titanium alloys offer a range of mechanical properties that make them ideal for varied applications such as corrosive-fluid pump shafts, cryogenic storage vessels, rocket engine cases, heat-exchangers, jet engine compressor wheels, blades and spacers, airframe skins and structures (the Supersonic Transport Airplane Design makes extensive use of titanium and its alloys), chlorine anodes, saline water conversion units, deep diving undersea vehicles, tank armor, hydrofoil components, etc.

In some of these above-mentioned applications, the electrical characteristics of the metal and its alloys are very important and may be critical; especially if a film of titanium oxide is involved. A titanium oxide film is insulating and can have a rectifying action.

The following table compares the electrical resistivity of pure titanium with other pure metals: (at room temperature):

Titanium	47.8	microhm-cm
Magnesium	4.6	"
Aluminum	2.824	"
Iron	10.0	"
Copper	1.724	"

Because of the wide variety of titanium alloys which have been developed to date and their varied designations or codes, a chart or table listing the code designation and approximate chemical composition is also incorporated herein. Unfortunately, it does not list every commercially available alloy.

A few typical graphs are included herein to show the effect of alloying on the electrical resistivity of titanium and their variation with temperature. The electrical properties of titanium at cryogenic temperatures are also enclosed in another set of curves. One reason for the wide scatter in property data points

is the effect of interstitial impurity elements such as nitrogen, oxygen which are easily dissolved in the titanium lattice because of the gettering characteristic of titanium. Hence, the amount of control exercised by each manufacturer with regard to the gaseous impurities and other metallic elements will govern the resulting electrical properties as well as other properties, e.g., hardness, tensile strength, etc.

A comprehensive data sheet covering all the electrical properties of titanium and its alloys will be started in the near future.

A wealth of technical data on the mechanical, chemical, physical, and thermal properties of titanium and its alloys can be obtained from the Defense Metals Information Center, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio.

# TITANIUM ALLOY PROPERTIES

MATERIAL	PRODUCT	COMPOSITION (% M.A.)	TESTING METHOD	TESTING METHOD	
				TENSILE STRENGTH psi	ELASTIC MODULUS psi
A-32	Electric Titanium Inc.	90 + Ti	S.B. W.I.T.	50,000	20,000
EC-42	Republic Steel Corp.	CP; 0.22 C	S.B. E.W.T.	50,000	20,000
Ti-25A	Vacuum Metals Corp.	90 + Ti; 0.12 Fe; 0.05 Mn; 0.10 C	S.B. E.W.T.	55,000	20,000
Ti-65A	Titanium Metals Corp.	90 + Ti; 0.12 Fe; 0.05 Mn; 0.10 C	S.B. E.W.T.	65,000	20,000
ES-55	Republic Steel Corp.	CP; 0.20 C	S.B. E.W.T.	55,000	20,000
A-55	Dem-Ore Titanium Inc.	CP; 0.20 C	S.B. E.W.T.	55,000	20,000
Ti-75A	Titanium Metals Corp.	90 + Ti; 0.20 C	S.B. E.W.T.	55,000	20,000
ES-70	Republic Steel Corp.	CP; 0.20 C	S.B. E.W.T.	55,000	20,000
E-70	Rem-Cru Titanium Inc.	90 + Ti; 0.20 C	S.B. E.W.T.	55,000	20,000
HAST 311	Mallory-Sharon Titanium Corp.	90 + Ti; 0.10 C	S.B. E.W.T.	55,000	20,000
A-110AT	Dem-Cru Titanium Inc.	22 Ti; 5 Al; 2.50 Sn	S.B. E.W.T.	55,000	20,000
ES-110A	Republic Steel Corp.	7 Mn; 0.20 C	S.B. E.W.T.	55,000	20,000
ES-110SX	Republic Steel Corp.	3 Mn; 1.50 Al; 0.20 C	S.B. E.W.T.	55,000	20,000
C-110W	Rem-Cru Titanium Inc.	91 + Ti; 8 Mn	S.B. E.W.T.	55,000	20,000
Ti-102A	Titanium Metals Corp.	93 + Ti; 2 Fe; 2 Cr; 2 Mn; 0.24 Mn; 0.10 C	S.B. E.W.T.	55,000	20,000
C-110EV	Rem-Cru Titanium Inc.	93 + Ti; 6 Al; 4 V	S.B. E.W.T.	55,000	20,000
Y-22A-LV	Titanium Metals Corp.	93 + Ti; 6 Al; 4 V; 0.25 Fe; 0.05 Ni	S.B. E.W.T.F.E.	55,000	20,000
BEST 6 Al 4 V	Mallory-Sharon Titanium Corp.	5.50 to 6.50 Al; 3.50 to 4.50 V; 0.20 C	S.B. E.W.T.F.E.	55,000	20,000
BEST 8 Mn	Mallory-Sharon Titanium Corp.	92 Ti; 7 to 9 Mn; 0.20 C	S.B. E.W.T.F.E.	55,000	20,000
C-120AM	Rem-Cru Titanium Inc.	91 + Ti; 4 Mn	S.B. E.W.T.	55,000	20,000
ES-132	Republic Steel Corp.	4 Mn; 6 Al; 0.20 C	S.B. E.W.T.F.E.	55,000	20,000
BEST 4 Mn 6 Al	Mallory-Sharon Titanium Corp.	3.50 to 4.50 Mn; 3.50 to 4.50 Al; 0.20 C	S.B. E.W.T.F.E.	55,000	20,000
ES-160K	Republic Steel Corp.	1.25 Fe; 2.75 Cr; 5 Al; 0.20 C	S.B. E.W.T.F.E.	55,000	20,000
KJ-3 Al 5 Cr	Mallory-Sharon Titanium Corp.	2.50 to 3.50 Al; 4.50 Cr; 5.50 Cr; 0.20 C	S.B. E.W.T.F.E.	55,000	20,000
Ti-155A	Titanium Metals Corp.	8% + Ti; 1.30 Fe; 1.40 Cr; 1.40 Mn; 5 Al; 0.05 Ni; 0.10 C	S.B. E.W.T.F.E.	55,000	20,000

Fig.—Round bar products—sheet, strip, plate

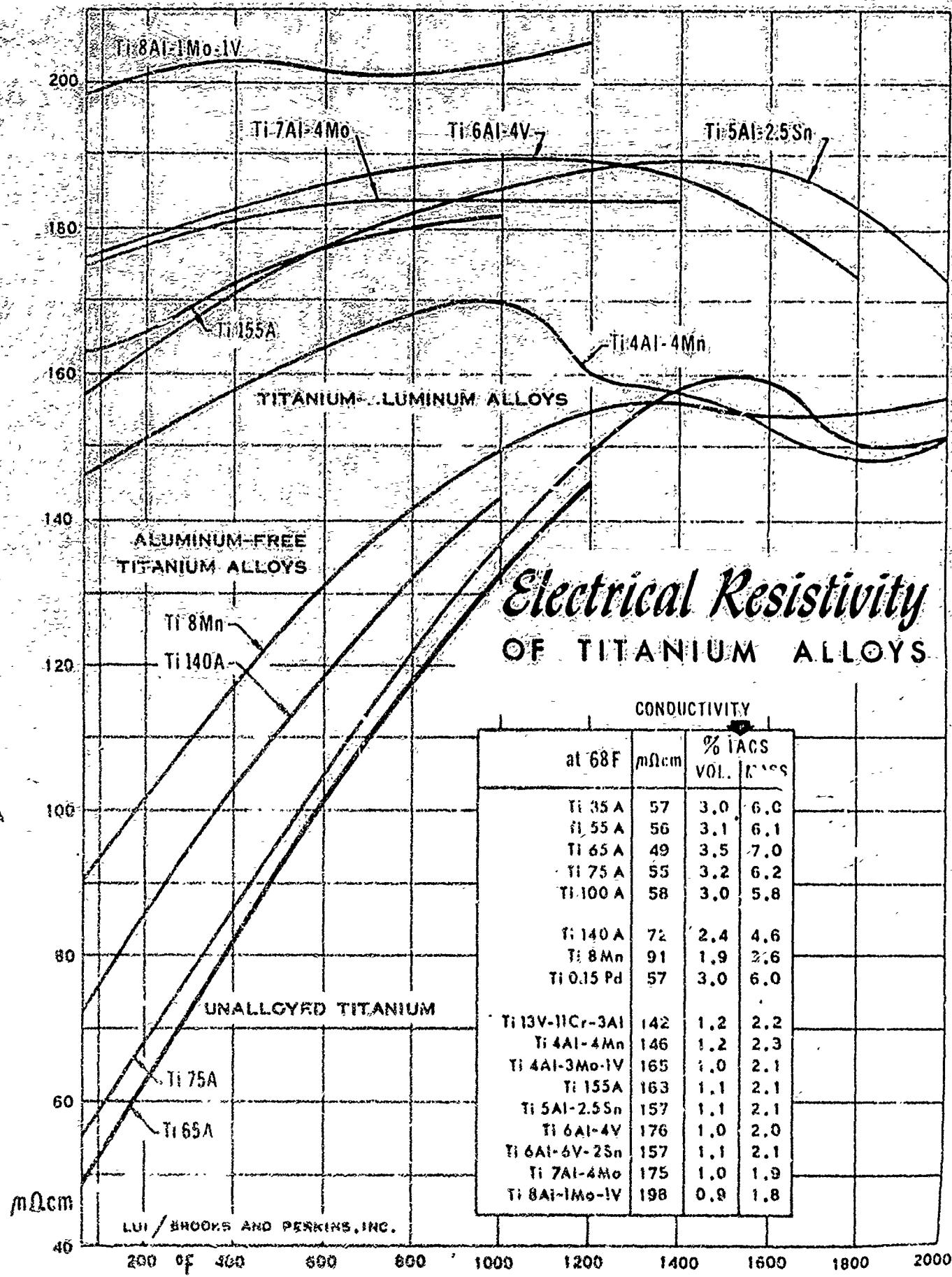
S—Bar and billet

E—Extrusions

W—Wire

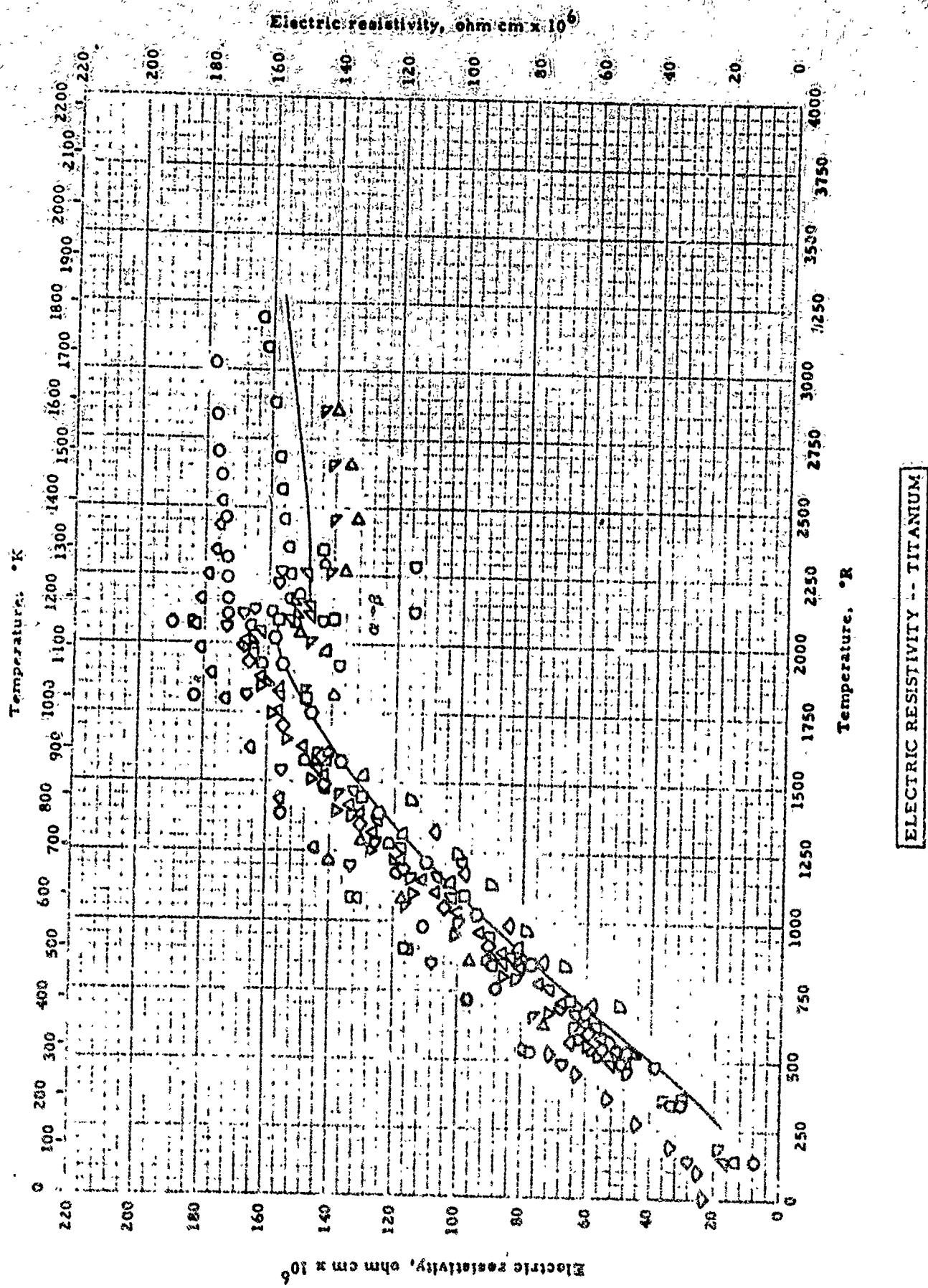
T-Tube

F-Forgings



**"ELECTRICAL RESISTIVITY OF TITANIUM METAL AND VARIOUS TITANIUM  
ALLOYS AS A FUNCTION OF TEMPERATURE AND ALLOY CONTENT."**

**Reference:** Alexander Goldsmith (Editor)  
Armour Research Foundation  
Handbook of Thermophysical  
Properties of Solid Materials.  
WADC-TR-58-476, November 1960  
AD 253 710



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ELECTRIC RESISTIVITY -- TITANIUM

**ELECTRIC RESISTIVITY -- TITANIUM**

**REFERENCE INFORMATION**

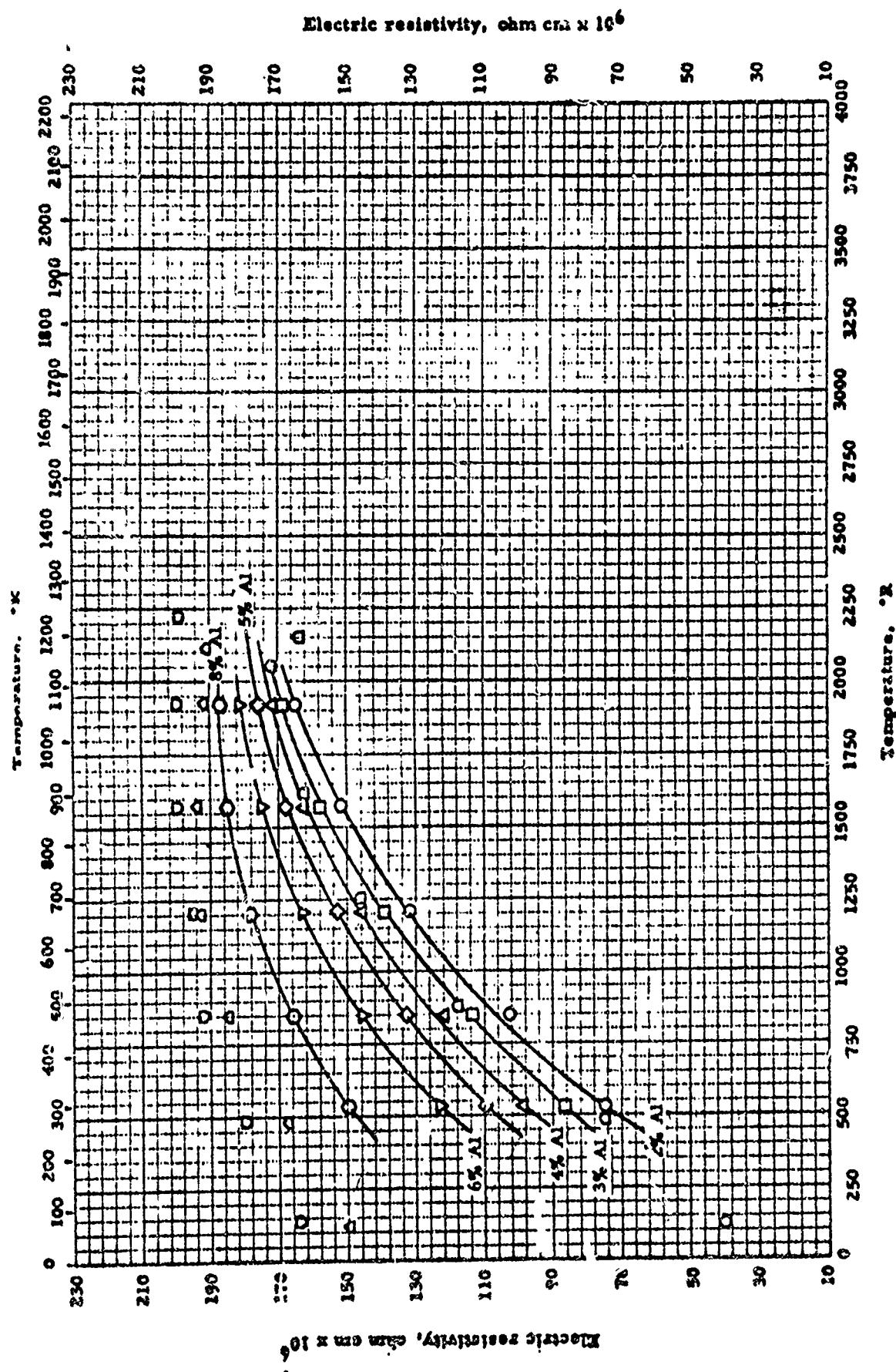
Ref. No.	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Part. J. L.	53-15	137-3033	"Iodide": 99.9% Ti; 0.06% Pb; 0.012% A; 0.010% Mn; 0.004% Fe; 0.003% Sn; 0.005% N; 0.001% ea. Cu, Mg	Kelvin bridge	Data reported as r/r (77°F). Auth. est. accuracy of $\pm 0.02$ ohm/cm at 77°F
D	Ames, S. L. and McQuillan, A. D.	54-25	750-2310	"Iodide titanium": 0.38% Zr	Kelvin bridge	Sample homogenized for 70 hr. at 1000°C, then quenched.
A	Weiner, L., Caiotti, P. and Wilhelm, H. A.	52-3	535-2018	"Iodide titanium"	Potential drop	Annealed 12 hr. at 650-700°C. Heating and cooling rates: 25-65°F/hr. Auth. est. accuracy of 0.4%
O	Bisic	52-8	541-1997	Same as above	Same as above	Annealed 10 hr. at 675-700°C. Heating rate: Other conditions as above
P	Part. J. L.	52-8	550-1997	Same as above	Potential drop	Annealed 8 hr. at 760-775°C. Heating rate: Other conditions as above
O	Ames, S. L. and McQuillan, A. D.	56-15	537-2021	"Iodide titanium": $\alpha$ -hexagonal modification	Kelvin bridge	High temp. work in vacuum of 10-6 mm Hg. Auth. est. accuracy 1%.
O	Part. J. L.	53-15	137-3195	Ti-75A: 99.74% Ti; 0.08% Si; 0.06% O <sub>2</sub> ; 0.03% Fe; Cl; 0.02% Mg; 0.015% Mn; 0.01% Al; 0.002% ea. N <sub>2</sub> , S <sub>2</sub> , Pb, W, Cr, Ni; 0.001% ea. Sn, Cu, V, Mo	Kelvin bridge	Data reported as r/r (77°F). Auth. est. accuracy of $\pm 0.02$ ohm/cm at 537°K. Auth. est. accuracy of $\pm 1\%$
O	Michelin, F. C. and G. J. G. S. E.	49-5	540-2520	Impure, commercial material	Potential drop	Potential drop
O	Buckley, W. C. and Willard, S. E.	49-8	527-2075	99.5% pure	Potential drop	Annealed 16 min. at 820°C
O	Werner, H. W.	49-7	519-573	0.2-0.3% Fe; 0.1% N <sub>2</sub> ; 0.07% C; trace of Pb, Si, Mn; faint trace of Mg, Zn, Cu, Co; p = 281 lb/in <sup>2</sup> /ft <sup>2</sup>	Kelvin bridge	Annealed 5 hr. at 950°C in vacuum
O	Kemp, W. R. C. et al.	56-14	0-522	Normal 93% purity, 1.63% O <sub>2</sub> ; 0.14% C; 0.13% Si; 0.061% Ni; 0.05% Fe	Potential drop	High temp. work in vacuum of 10 <sup>-6</sup> mm Hg. Auth. est. accuracy 1%.
A	Ames, S. L. and McQuillan, A. D.	56-15	492-1842	Iodide refined ( $\alpha$ -phase): 1% Nb	Kelvin bridge	Annealed 5 hr. at 700°C in vacuum
D	Mikryukov, V. E.	57-50	560-1440	"Iodide titanium": 99.9% pure	Potential drop	Same as above
O	Bid.	57-50	565-1320	Forged Titanium 99.6% pure	Kelvin double bridge	Same as above
A	Bostrom, W. A.	57-100	139-2256	Crystal bar: 0.07% O <sub>2</sub> ; 0.032% C	Commercial grade: 0.57% C; 0.16% C <sub>2</sub> ; 0.05%	Same as above
O	Bid.	57-100	139-2256	Commercial grade: 0.57% C; 0.16% C <sub>2</sub> ; 0.05%	Double bridge method at high temp., and knife edges at normal temp.	Same as above
D	Ames, S. L. and McQuillan, A. D.	56-95	1272-2292	p phase		

ELECTRIC RESISTIVITY -- TITANIUM (Cont'd)

REFERENCE INFORMATION

Ref.	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
G	Peterson, V. C. and Huber, R. W.	55-101	492-2292	Not given	Potential drop	Gold swaged and drawn, annealed 2 hr. at 800 °C. A to β transformation causes drop of res. at 884-896 °C.
D	Sagel, K.	56-96	528-2157	99.99% pure	Not given	Iodide titanium
D	Deem, H. W., Wood, W. D. and Lucks, C. F.	58-21	1360-1160	A-55 (formerly RC-55); unalloyed norm. 100% Ti	Potential drop	Auth. est. accuracy ± 1%
G	Greiner, E. S. and Ellis, W. C.	48-23	139-1948	"Ductile" Ti	Potentiometer. Current reversed; Cu-Const. thermocouple low temp. Chromel-Alumel thermocouple high temp. Room temp. in oil bath	Two samples (graphically identical) Sample A annealed, sintered compact, cold swaged with intermediate vac. annealing at 800-1000 °C.
D	<i>Bid.</i>	48-23	528-1932	Same as above	Same as above	Sample B rod cold swaged with intermediate annealing at close packed hex - body. Annealed 2 hr. in vacuum at 800 °C
D	Lampson, F. K., Rowe, G. H., et al.	54-102	528-2960	99.99% pure; 0.10% Fe; 0.02% N <sub>2</sub> ; low C <sub>3</sub>	Potential drop, He atmos.	Same as above
D	<i>Ibid.</i>	54-102	528-2960	Same as above	Potential drop	Grain growth 20 fold during test. Auth. believes broad trans. range and decrease in resistivity due to impurities. Heating
D	Munster, A., Sagel, K. and Zerkner, U.	56-112	528-2148	Pure iodide Ti	Same as above. Cooling Difference between heating and cooling runs less than 5%	Same as above. Cooling

ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM  
(0 - 10% Al)

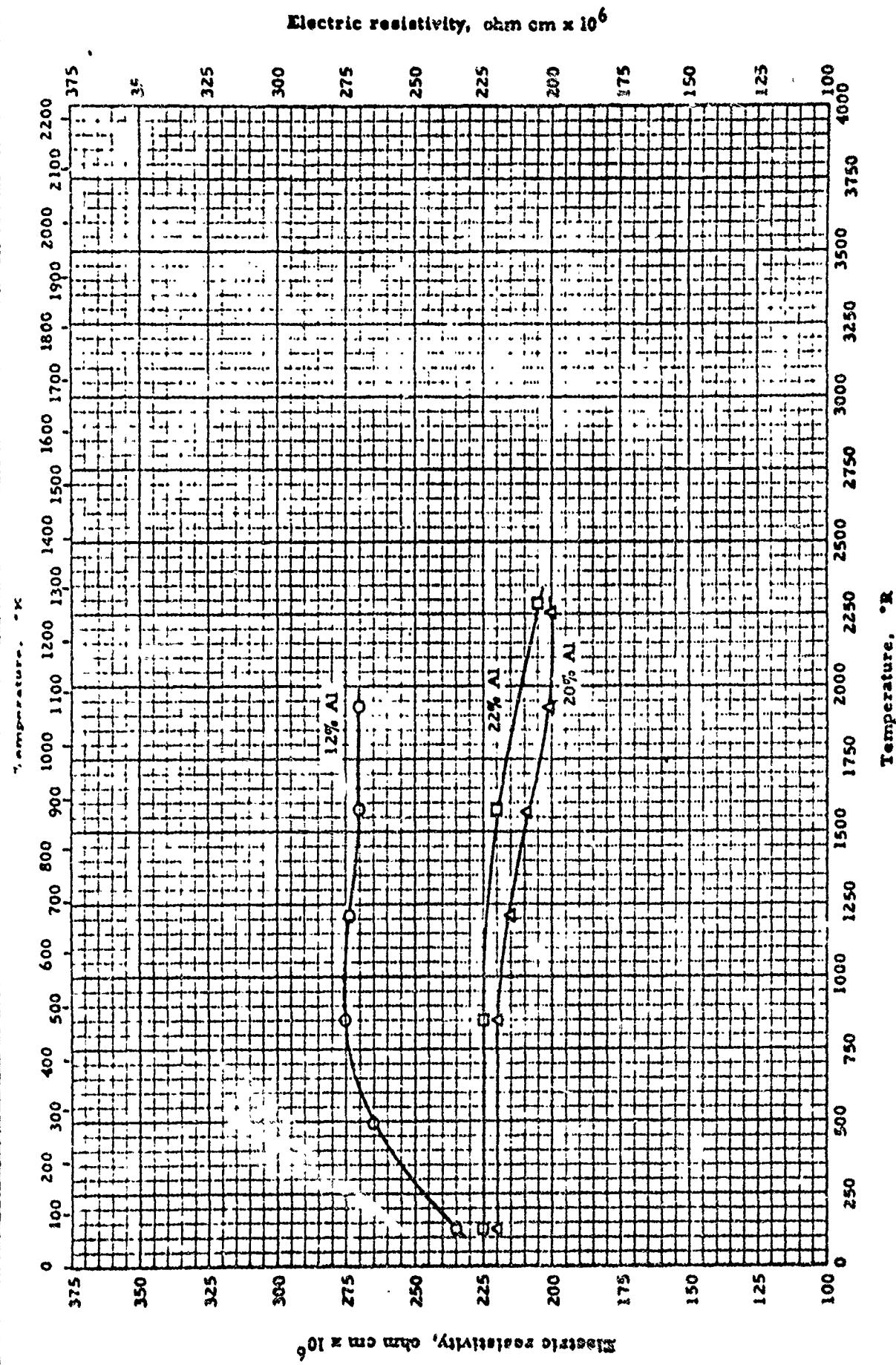


ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM  
(0 - 10% Al)

REFERENCE INFORMATION

Symbo	Investigator	Ref.	Range. *R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	56-15	537-1932	Ti, $\alpha$ -phase; 2% Al	Double balance bridge	High temp. work in vacuum of 10-6 mm Hg. Auth. est.
□	Ibid.	56-15	537-1932	Ti, $\alpha$ -phase; 3% Al	Same as above	Same as above
△	Ibid.	56-15	537-1932	Ti, $\alpha$ -phase; 4% Al	Same as above	Same as above
◊	Ibid.	56-15	537-1932	Ti, $\alpha$ -phase; 5% Al	Same as above	Same as above
▽	Ibid.	56-15	537-1932	Ti, $\alpha$ -phase; 6% Al	Same as above	Same as above
○	Ibid.	56-15	537-1932	Ti, $\alpha$ -phase; 8% Al	Same as above	Same as above
○	Munster, A. Sagel, F. and Zwicker, U.	56-112 also 56-96	150-2148	1% Al	Potential drop	Made from pure iodide-titanium or 99.96% pure Mg-reduced Ti and 99.99% pure Al. Melted in arc furnace with W electrode, in 99.995% pure Ar atm., remelted twice more. Diff. between heating and cooling < 3%
○	Ibid.	56-112 also 56-96	150-2094	7% Al	Same as above	Same as above
○	Ibid.	56-112 also 56-96	150-2220	8% Al	Same as above	Same as above
				"		

ELECTRIC RESISTIVITY - TITANIUM + ALUMINUM  
(10 - 22% Al)

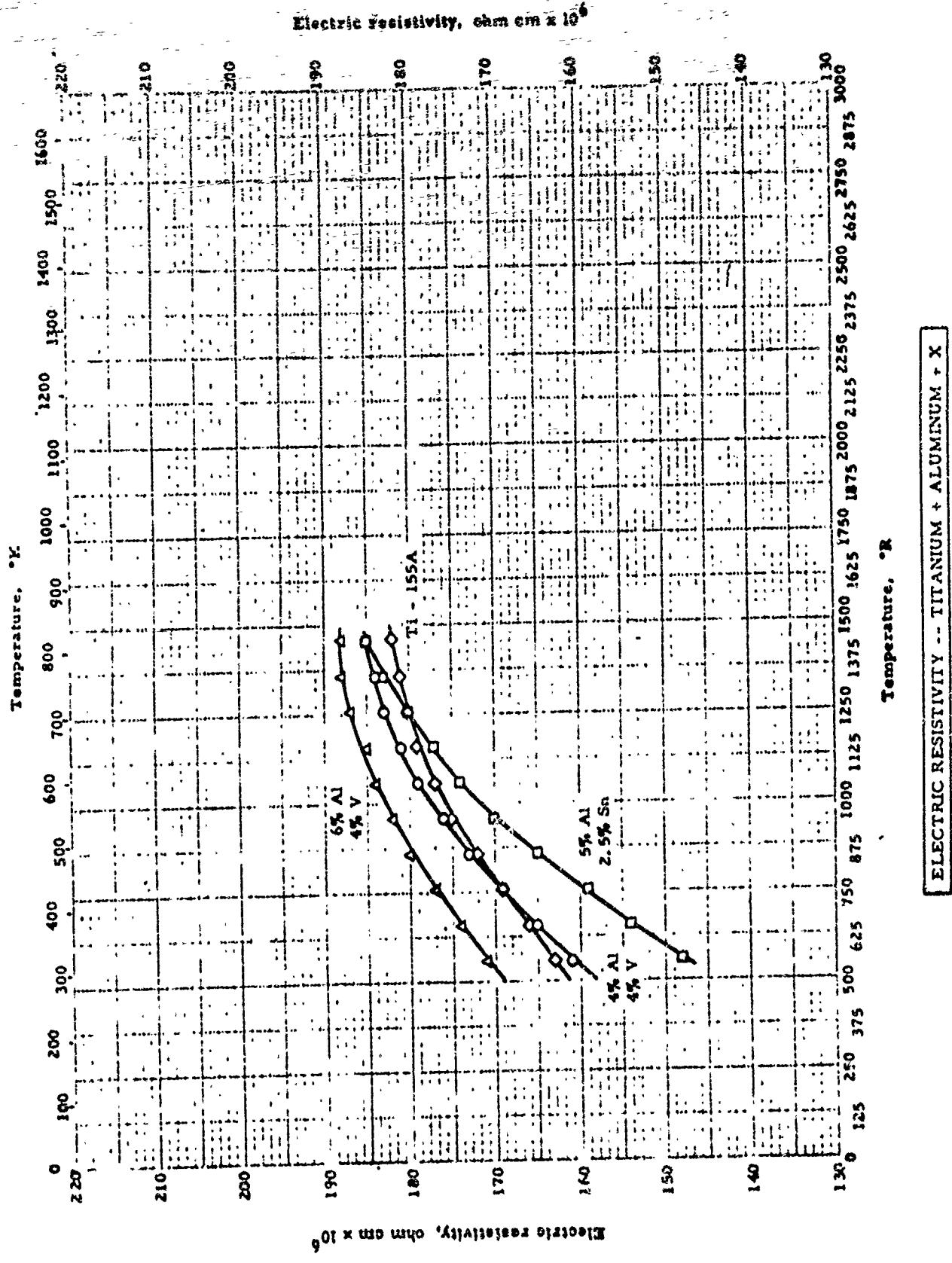


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ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM  
(10 - 22% Al)

REFERENCE INFORMATION

Sym. bol	Investigator	Ref.	Range, "R"	Material Composition	Test Method	Remarks
C	Münster, A., Sagel, K. and Zwicker, G.	56-96 also 56-112	150-2292	12% Al	Potential drop	Prepared from iodide Ti or 99.96% pure Mg - reduced Ti and 99.99% pure Al, melted in arc furnace with W electrode in 99.995% pure Al, and remelted twice more. Diff. between heating and cooling runs less than 3%.
A	Ibid.	56-96 also 56-112	150-2004	20% Al	Same as above	Same as above
C	Ibid.	56-96 also 56-112	150-2220	22% Al	Same as above	Same as above



ELECTRIC RESISTIVITY - TITANIUM + ALUMINUM + X

V - C - 1

ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM + X

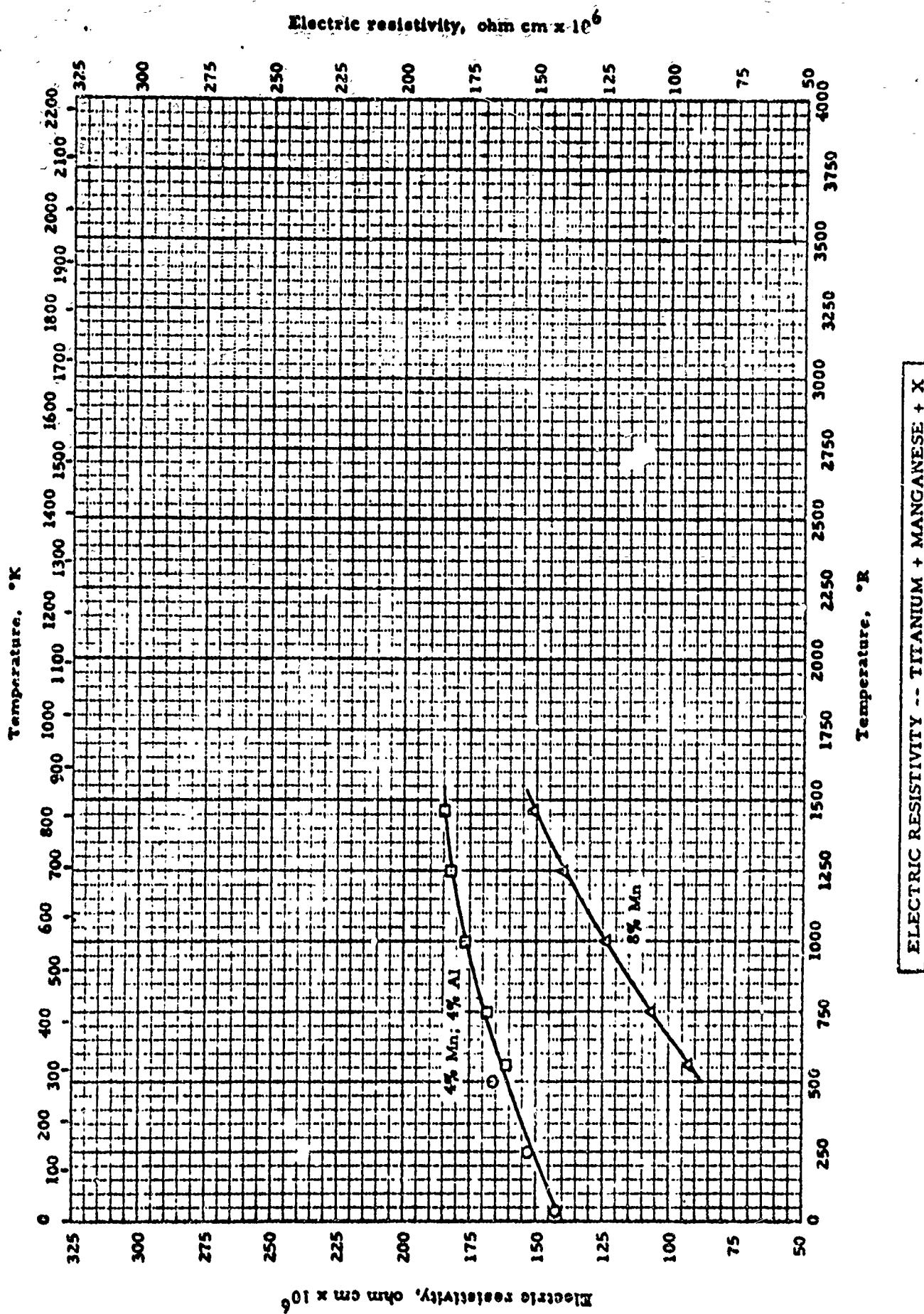
REFERENCE INFORMATION

Spec No.	Investigator	Ref.	Range, R	Material Composition	Test Method	Remarks
O	Deem, H. W., Wood, W. D. and Lucke, C. F.	56-21	560-1460	C - 1.30 AM (Formerly RC-13RB) Nominal: 4% Al; 4% Mn	Potential drop	Auth. test. accuracy $\pm 1\%$
D	Did	56-21	560-1460	A-110 AT Nominal: 5% Al 2.5% Sn	Same as above	Same as above
A	Did	56-21	560-1460	T1-6-Al-4V Nominal: 6% Al, 4% V	Same as above	Same as above
O	Did	56-21	56C-1460	T1-15SA Nominal: 5% Al; 1.5% Fe; 1.4% Cr; 1.2% Mo	Same as above	Same as above

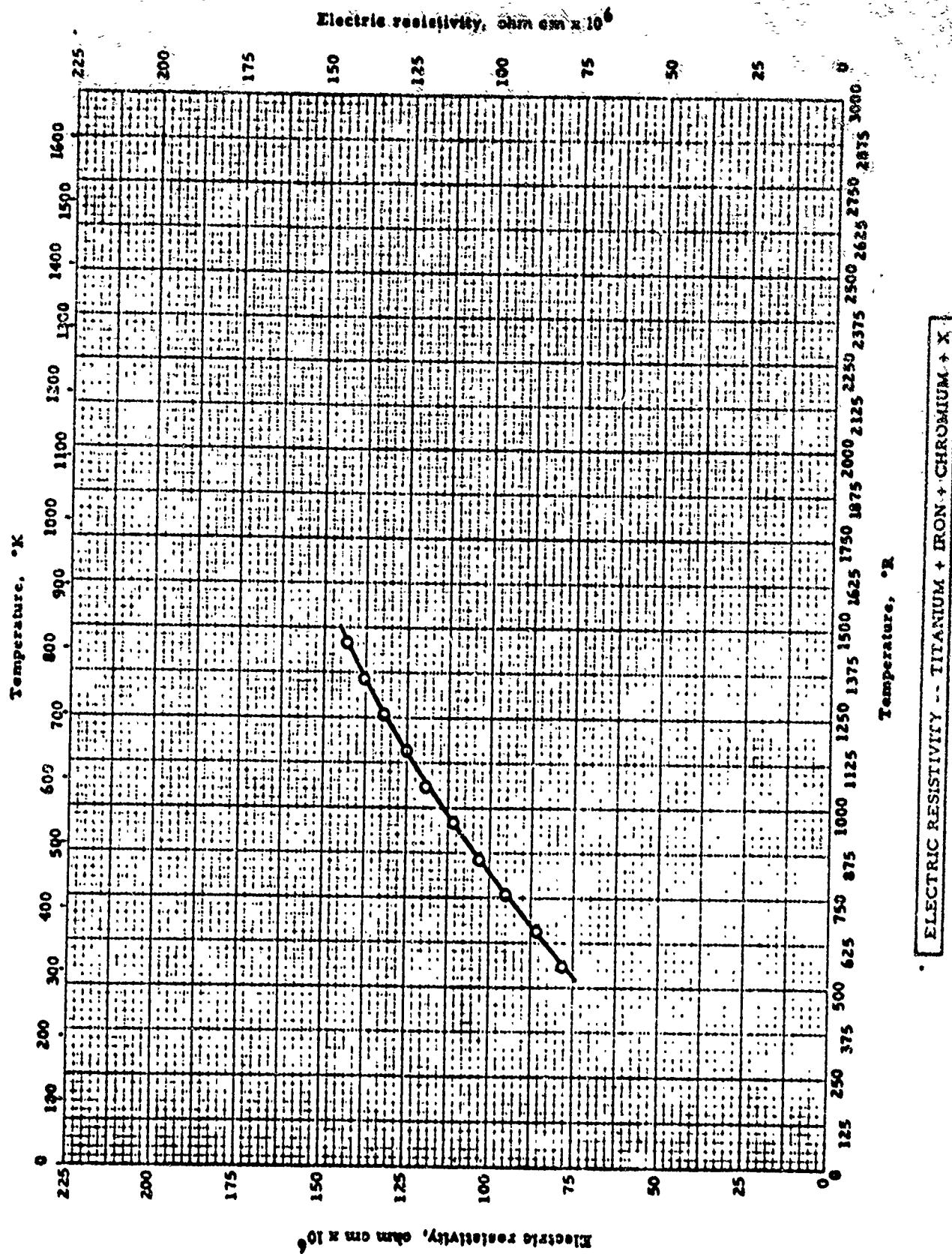
## LINEAR THERMAL EXPANSION -- TITANIUM + MANGANESE + X

## **REFERENCE INFORMATION**

Sym bol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Bishop, S. M., Spretnak, J. W. and Fontana, M. G.	52-122	130-530	Ti-150-A. 3.8% Mn; 3.8% Al; 0.24% C	Quartz tube dilatometer with dial gauge. Temp. by thermocouple	Annealed 6 hr. at 1200 °F



ELECTRIC RESISTIVITY -- TITANIUM + MANGANESE + X



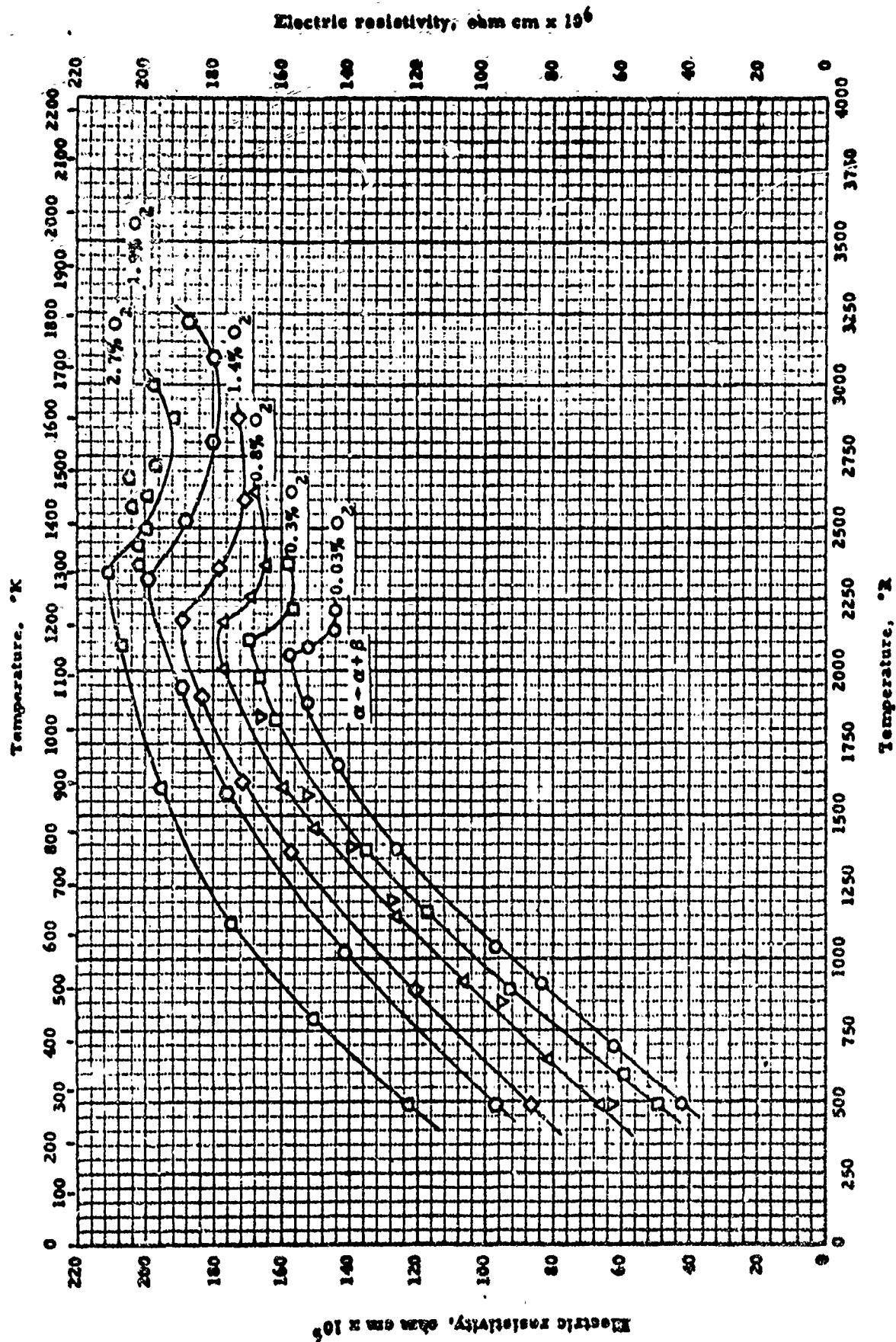
V - C - 7

ELECTRIC RESISTIVITY -- TITANIUM-IRON-CHROMIUM-X

REFERENCE INFORMATION

Ref.	Investigator	Ref.	Ranges, "R"	Material Composition	Test Method	Remarks
O	Decm. H. W., Wood, W. D. and Locke, C. F.	58-21	550-1460	Ti-140A. Nominal: 2. 2% Fe; 2.1% Cr; 2.0% Mo	Potential drop	Avg. est. accuracy $\pm 1\%$

ELECTRIC RESISTIVITY -- TITANIUM + OXYGEN + X

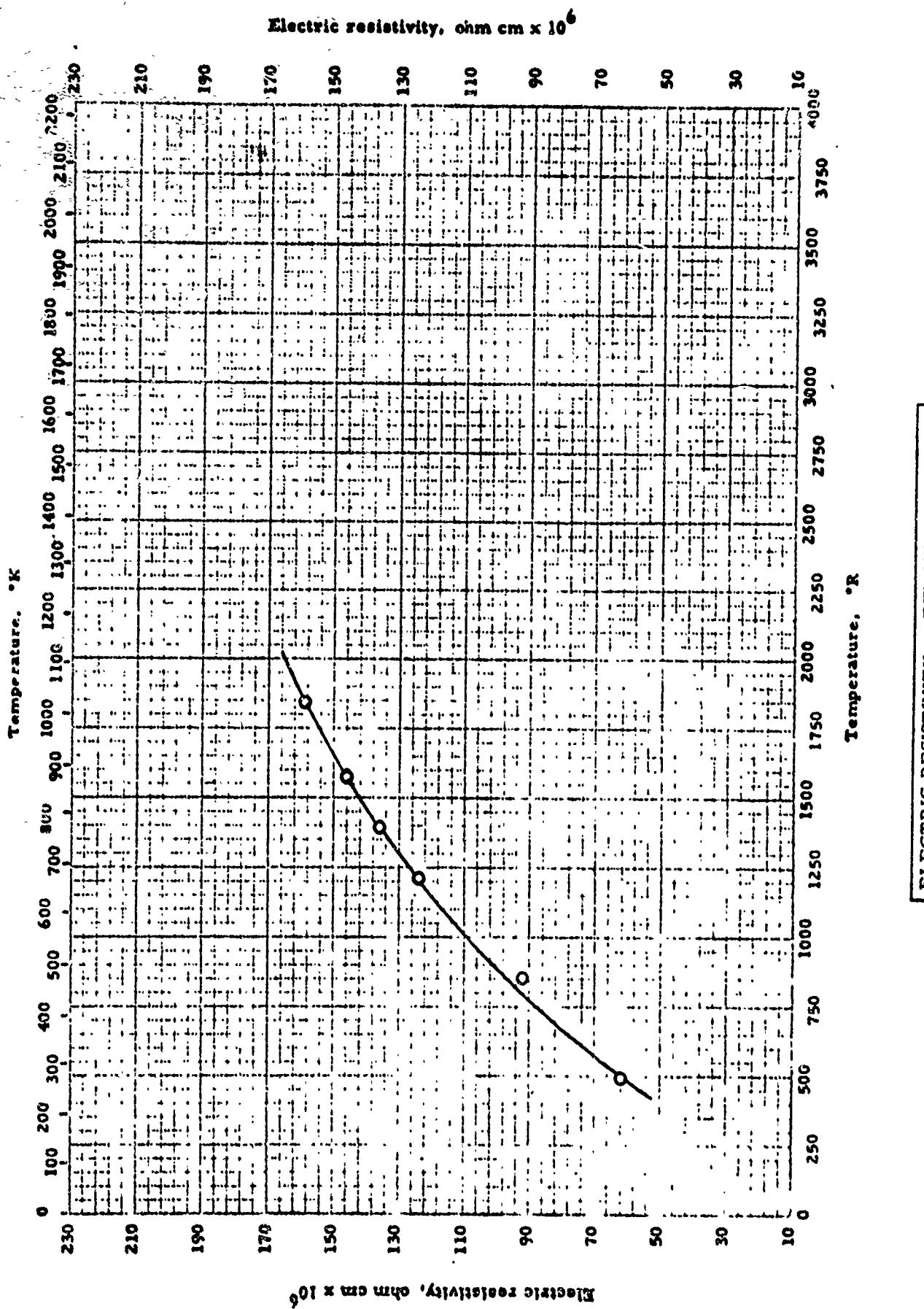


V - C - 6

ELECTRIC RESISTIVITY -- TITANIUM + OXYGEN + X

REFERENCE INFORMATION

Syn. Sol.	Investigator	Ref.	Range, "R"	Material Composition	Test Method	Remarks
O	DePue, L. A., and Chapin, E. J.	56-9	492-2216	0.028% O <sub>2</sub> ; 0.002% N <sub>2</sub> ; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Potential drop	High purity iodide titanium and pure TiO <sub>2</sub> fused in He atmos., and remelted several times
O	Ibid.	56-9	492-2221	0.015% O <sub>2</sub> ; 0.001% N <sub>2</sub> ; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above
O	I. W.	56-9	492-2638	0.848% O <sub>2</sub> ; 0.002% N <sub>2</sub> ; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above
O	Ibid.	56-9	492-2891	1.40% O <sub>2</sub> ; 0.002% N <sub>2</sub> ; Mo, Al, Si, Cu Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above
V	Annes, S. L., and McQuillan, A. D.	56-15	492-1842	1.45% O <sub>2</sub>	Double balance bridge	Prepared from iodide re- fused (X-phase) titanium and spectroscopically pure TiO <sub>2</sub>
O	DePue, L. A., and Chapin, E. J.	56-9	492-3223	1.90% O <sub>2</sub> ; 0.003% N <sub>2</sub> ; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Potential drop	High purity iodide titanium and pure TiO <sub>2</sub> fused in He atmos., and remelted sever- al times
O	Ibid.	56-9	492-2994	2.68% O <sub>2</sub> ; 0.006% N <sub>2</sub> ; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above

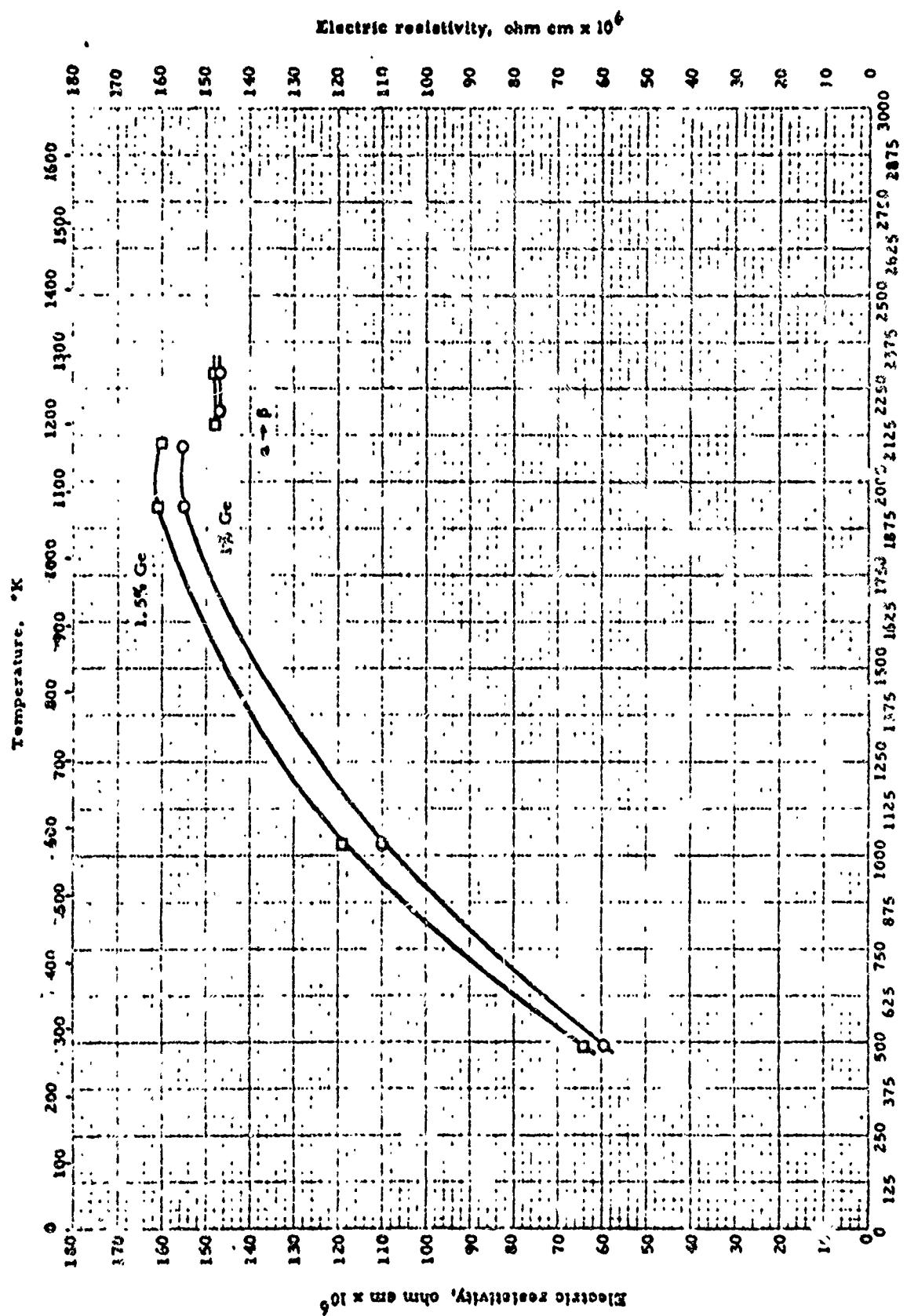


V - C

ELECTRIC RESISTIVITY -- TITANIUM + COPPER

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, "R"	Material Composition	Test Method	Remarks
O	Ames, S. L. and McQuillan, A. D.	56-15	492-1842	Iodide Ti ( $\alpha$ -phase); 1% Cu (99.99% pure)	Double balance bridge	High temp. work in vacuum of 10 <sup>-6</sup> mm Hg. Auth. est. accuracy 1%



Temperature, °R

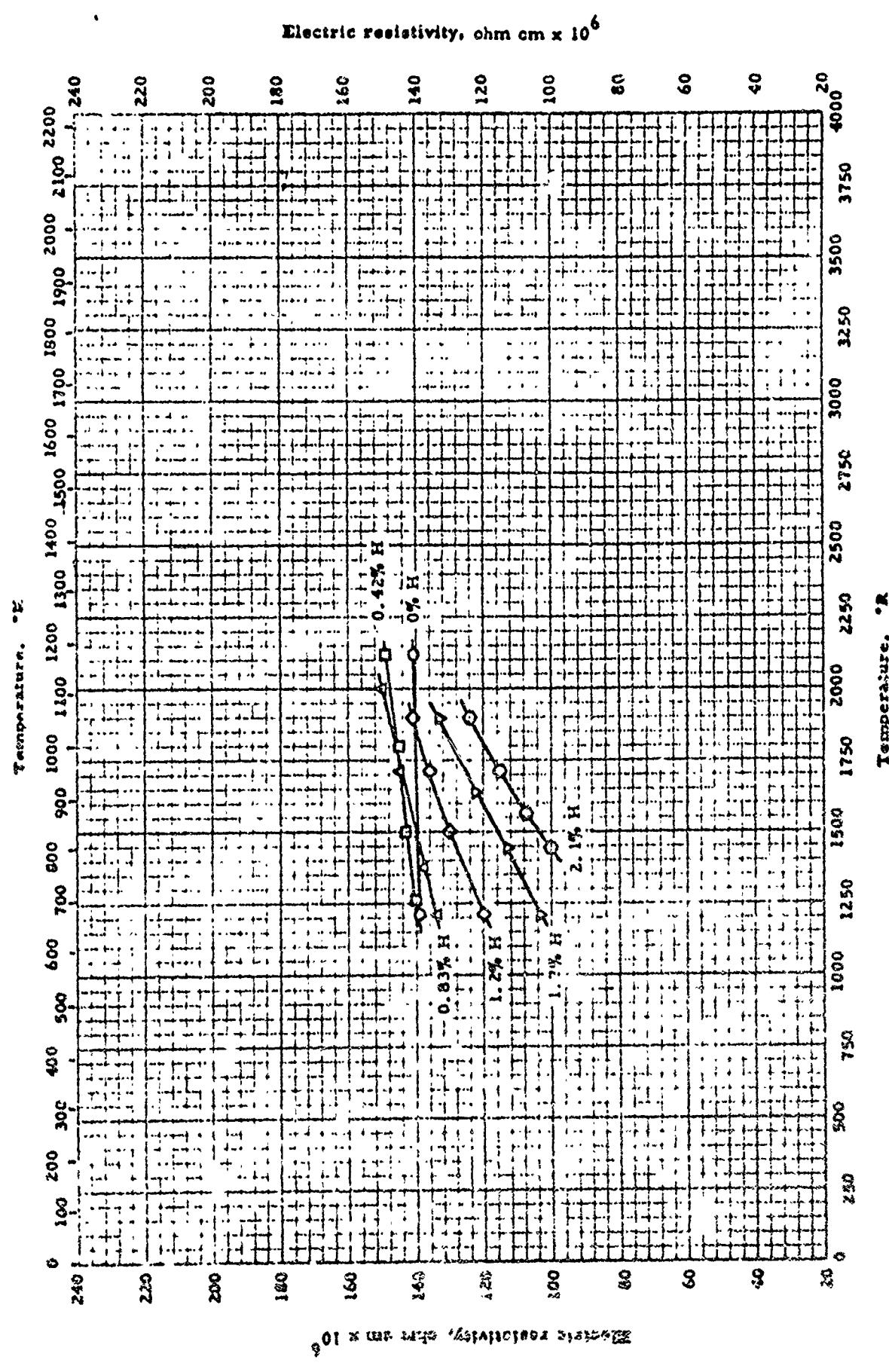
ELECTRIC RESISTIVITY -- TITANIUM + GERMANIUM

ELECTRIC RESISTIVITY :- TITANIUM + GERMANIUM

REFERENCE INFORMATION

Sym bol	Investigator	Ref.	Range, "R"	Material Composition	Test Method	Remarks
O	Petersen, V. C. and Huber, R. W.	55-101	492-2292	99% Ti; 1% Ge	Potential drop	Heating rate 50 °C/min.
D	Ibid.	55-101	492-2292	98.5% Ti; 1.5% Ge	Same as above	Same as above

ELECTRIC RESISTIVITY - TITANIUM + HYDROGEN



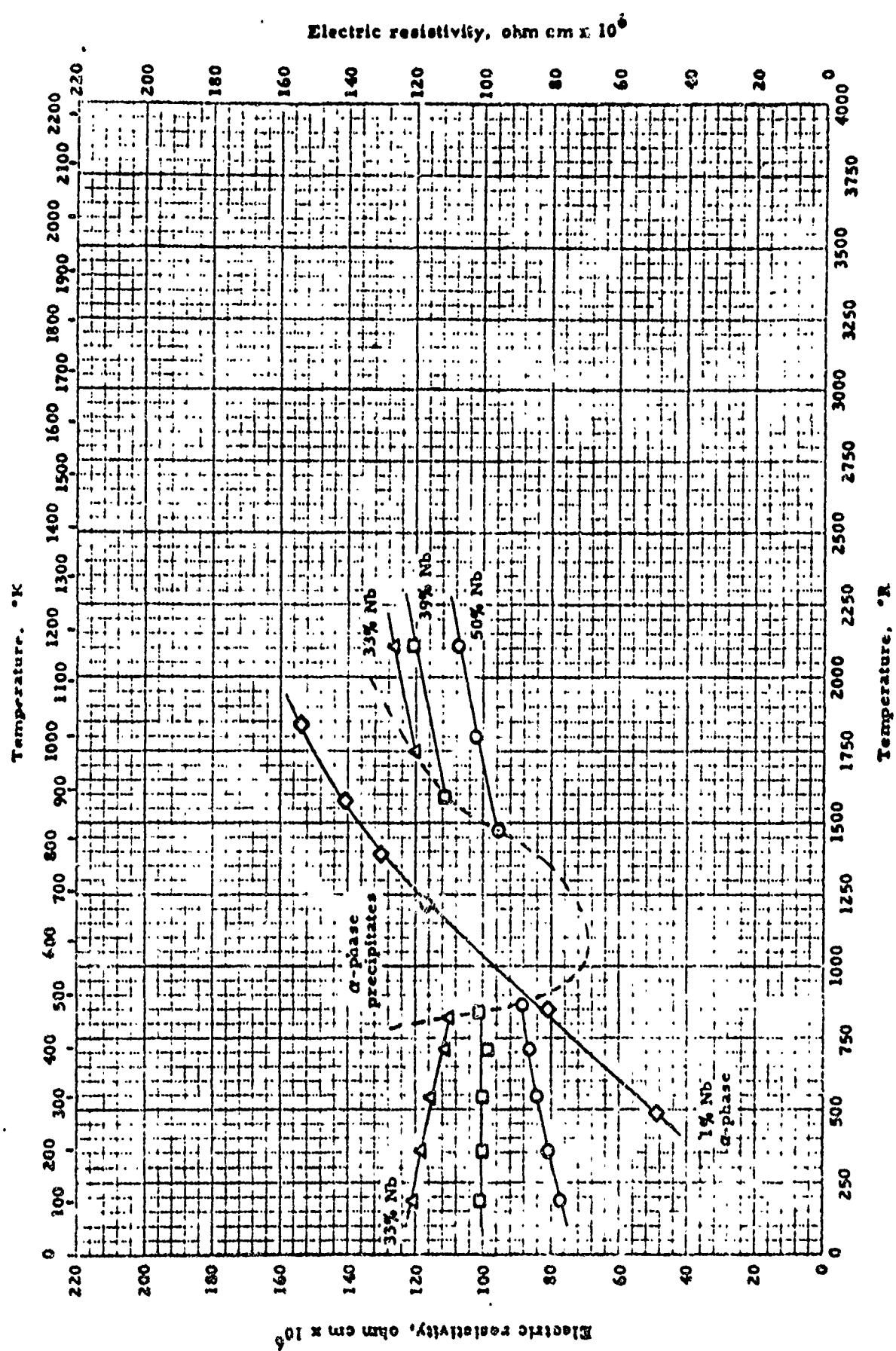
V - C

ELECTRIC RESISTIVITY -- TITANIUM + HYDROGEN

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Amer, S. I. and McQuillin, A. D.	56-95	1212-2119	0% H	Double bridge	Rod of iodide-titanium in equilibrium with H <sub>2</sub> atm.
D	Ibid.	56-95	1212-2119	0.42% H	Same as above	
D	Ibid.	56-95	1212-2000	0.83% H	Same as above	
A	Ibid.	56-95	1212-1896	1.2% H	Same as above	
O	Ibid.	56-95	1212-1896	1.7% H	Same as above	
V	Ibid.	56-95	1212-1896	2.1% H	Same as above	
O	Ibid.					Same as above

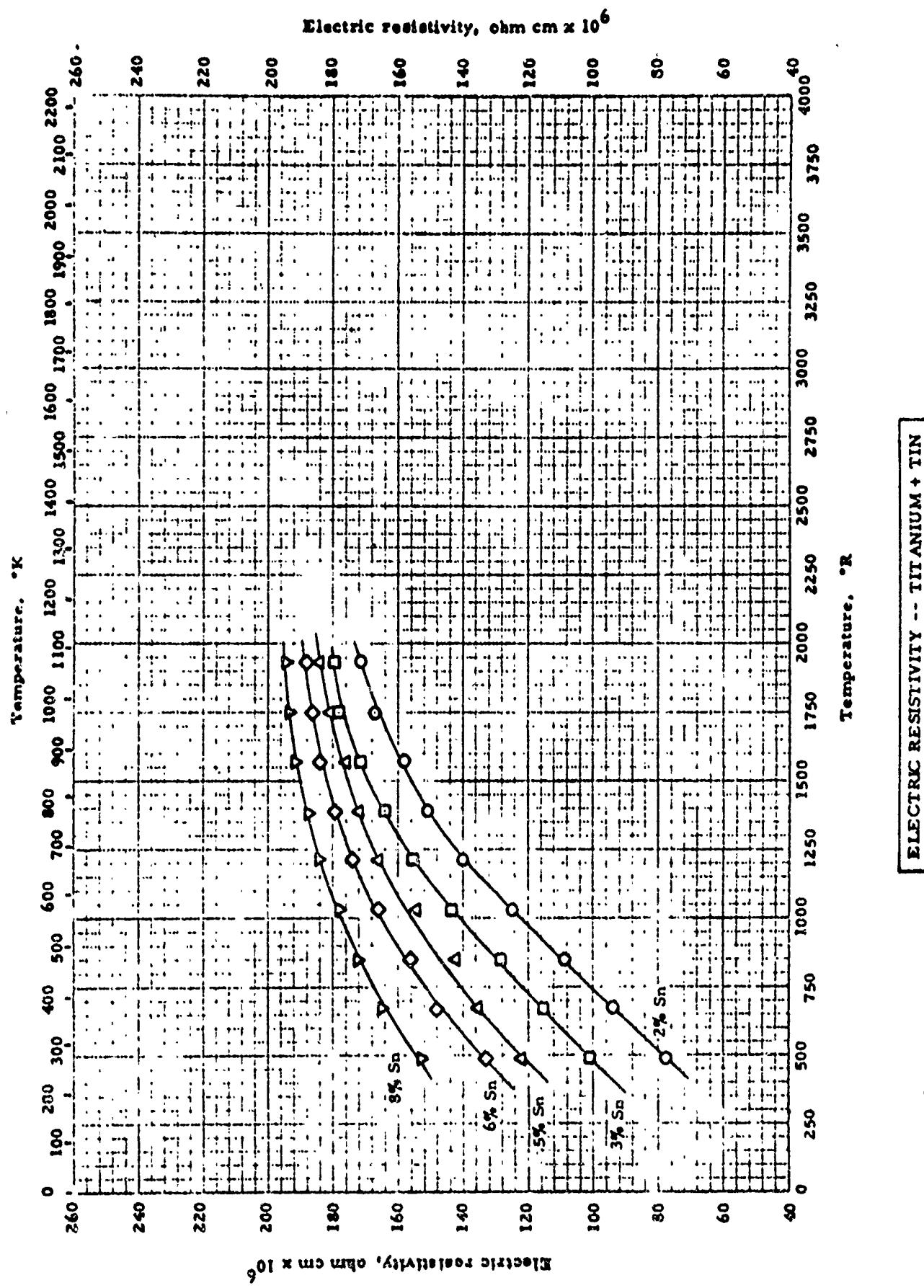
ELECTRIC RESISTIVITY -- TITANIUM + NIOBIUM



ELECTRIC RESISTIVITY -- TITANIUM + NIOBIUM

REFERENCE INFORMATION

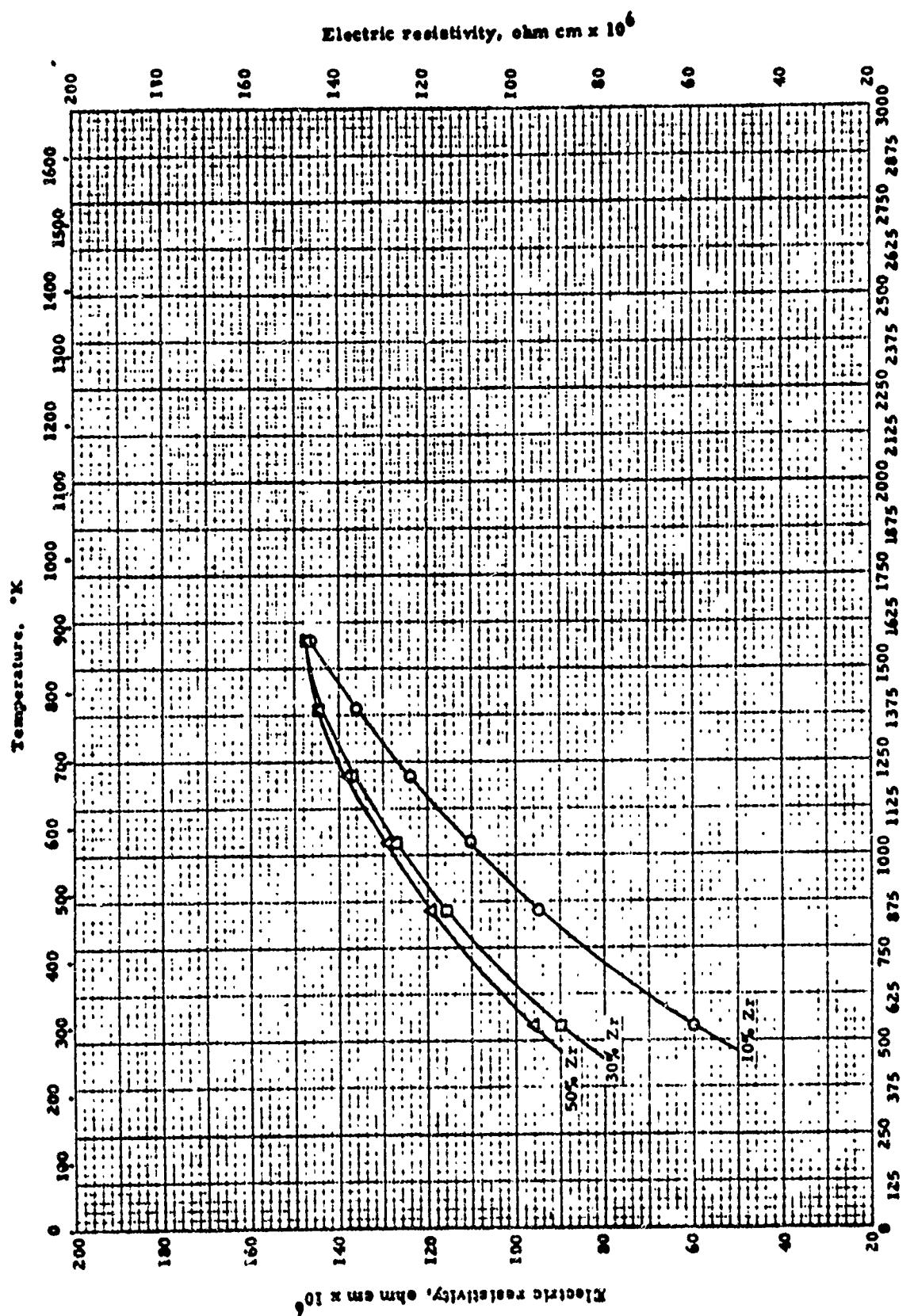
Sym bol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	54-25	180-2112	50% Ti; 50% Nb; β - phase; prepared from spectroscopically pure Nb and iodide refined Ti (0.2 atomic% Zr)	Double bridge	Cast, rolled, remelted, hot forged, surface layers re- moved, cold swaged, homo- genized 70 hr. at 1050°C in vacuum, quenched to retain β phase. Tested in vacuum
□	Ibid.	54-25	180-2112	60.7% Ti; 39.3% Nb; β - phase; raw materials same as above	Same as above	Same as above
△	Ibid.	54-25	180-2112	67.3% Ti; 32.7% Nb; β - phase; raw materials same as above	Same as above	Same as above
◊	Ames, S. L. and McQuillan, A. D.	56-15	492-1842	99% Ti; 1% Nb; α - phase; prepared from spectroscopically pure Nb and iodide refined Ti	Double bridge	Tested in vacuum. Auth. est. precision + 1%. Auth. states anisotropy may exist



ELECTRIC RESISTIVITY -- TITANIUM + TIN

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	56-15	492-1932	98% Ti; 2% Sn; $\alpha$ -phase; prepared from iodide refined Ti and 99.99% pure Sn	Double bridge	Aust. est. accuracy + 1%; states anisotropy may exist. Tested in vacuum
□	Bid.	56-15	492-1932	97% Ti; 3% Sn; $\alpha$ -phase; raw material same as above	Same as above	Same as above
△	Bid.	56-15	492-1932	95% Ti; 5% Sn; $\alpha$ -phase; raw material same as above	Same as above	Same as above
◇	Bia.	56-15	492-1932	94% Ti; 6% Sn; $\alpha$ -phase; raw material same as above	Same as above	Same as above
▽	Bid.	56-15	492-1932	92% Ti; 8% Sn; $\alpha$ -phase; raw material same as above	Same as above	Same as above



ELECTRIC RESISTIVITY -- TITANIUM + ZIRCONIUM

V - C

ELECTRIC RESISTIVITY -- TITANIUM + ZIRCONIUM

REFERENCE INFORMATION

Sym bol	Investigator	Ref.	Range, °K	Material Composition	Test Method	Remarks
O	Ames, S. L. and McQuillan, A. D.	56-15	537-1572	90% Ti; 10% Zr; $\alpha$ -phase; prepared from iodide refined Ti and iodide refined Zr (containing ~ 2.5% Hf)	Double bridge	Auth. est. accuracy $\pm 1\%$
D	Ibid.	56-15	537-1572	70% Ti; 30% Zr; $\alpha$ -phase; raw materi- als same as above	Same as above	Same as above
A	Ibid.	56-15	537-1572	50% Ti; 50% Zr; $\alpha$ -phase; raw materi- als same as above	Same as above	Same as above

1435 - Cryogenics Lab

A compilation of the graphs of metals at low temp  
WADD-TB-60-5-6, Part 4

17.141a

Dec '61

ELECTRICAL RESISTIVITY of TITANIUM, Ti  
(Atomic Number 22)

Source of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie,  
Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil,  
Springer-Verlag, Berlin (1959) pp. 1-46

Other References:

Clausing, P. and Maubis, G.; *Physica* 7, 245 (1927)  
Fast, J. D.; *Z. anorg. u allgem. Chem.* 241, 42 (1939)  
Meissner, W., Franz, H. and Westerhoff, H.; *Ann. Physik* (5) 13, 555  
(1932)  
Meissner, W. and Voigt, B.; *Ann. Physik* (5) 7, 761, 892 (1930)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K ( $\rho_{273}$ ) for titanium to be used in calculating electrical resistivity is listed below the authors' names labeling each individual curve on the graph. These curves should not be extrapolated to lower temperatures since titanium becomes a superconductor at 0.39°K.

The data for this graph were taken from the reference cited above under "Source of Data". The values taken from the Landolt-Börnstein tables are those reported by the authors listed above under "Other References". The original authors are used in labeling the three curves on the graph.

The data reported in the Landolt-Börnstein tables are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature, as listed in the following tabular data. The actual value of  $\rho_{273}$  is not available for the Meissner, Franz and Westerhoff data so a datum value reported by Fast ( $\rho_{273} = 42.0 \times 10^{-6}$  ohm-cm)

- is suggested for calculating values of resistivity from these ratios.
- Fast reports very small impurities in the single crystal sample used in determining  $\rho_{273}$ .

The Landolt-Börnstein tables list the sample used by Clausing and Maubis as polycrystalline with 0.16% tungsten impurity. The sample used by Meissner and Voigt is also reported as of a polycrystalline nature drawn from a melt with 0.25% impurities of unknown type. The sample used by Meissner, Franz and Westerhoff is reported as being drawn from a melt with very small impurities. No comments were made on the mechanical working or heat treatment of the samples.

(Continued on following page.)

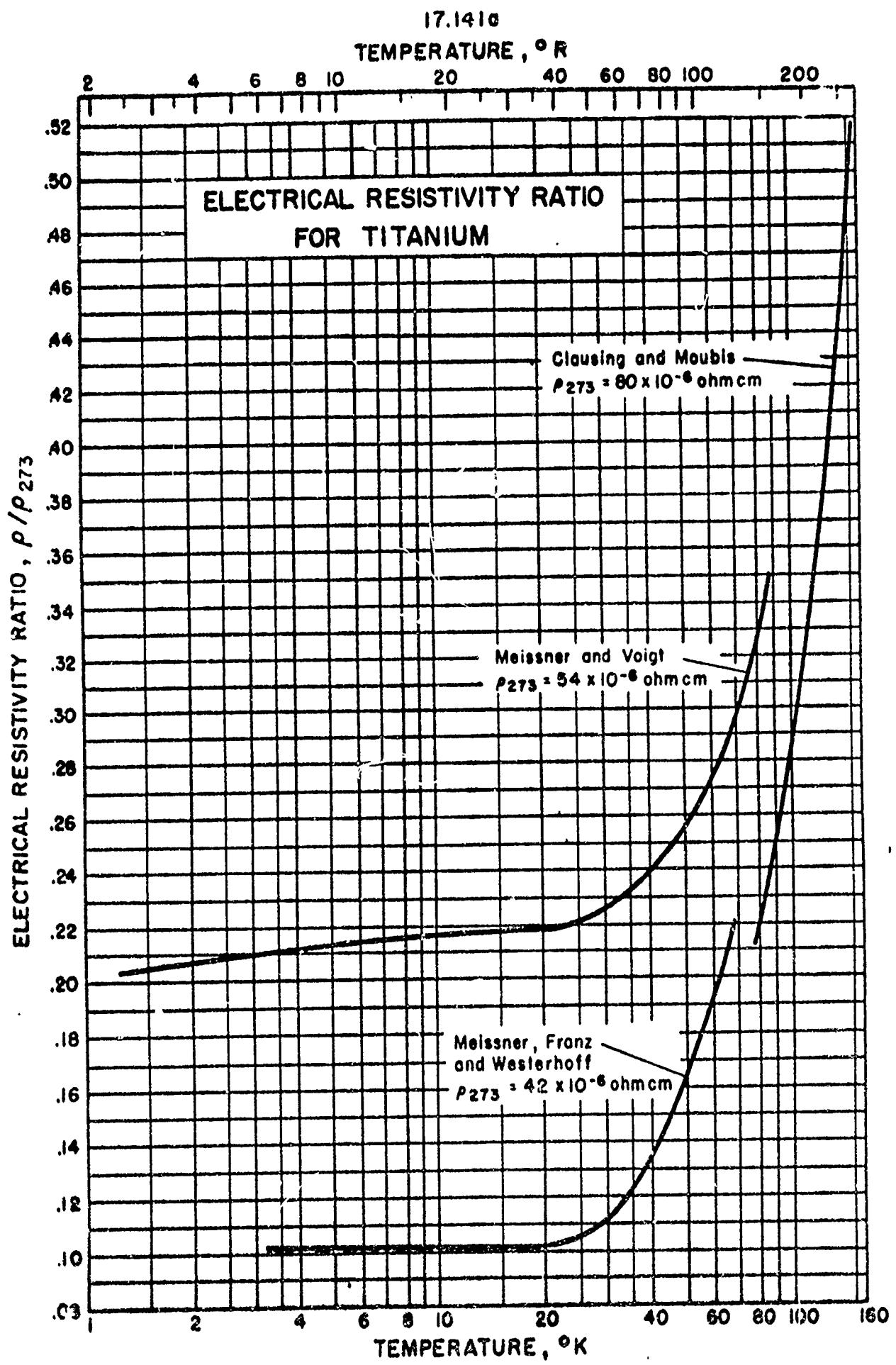
## ELECTRICAL RESISTIVITY OF TITANIUM (cont.)

Tables of Values of Electrical Resistivity $\rho$  = Resistivity, (ohm-cm) $\rho_{273}$  = Resistivity at 273°K, (ohm-cm)

Clausing & Moussis		Meissner, Franz & Westerhoff	
Temp. °K	$\rho/\rho_{273}$	Temp. °K	$\rho/\rho_{273}$
78.5	0.2150	3.24	0.102
90.2	0.2547	20.4	0.1015
158.5	0.5178	79.1	0.211

Meissner & Voigt	
Temp. °K	$\rho/\rho_{273}$
1.26	0.203
4.21	0.215
20.5	0.2180
88.2	0.3505

RDM/RS Issued: 1/18/61



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